Forward Look

"FARQUEST"

A foresight activity on research and technology in quantum information science and European strategy

Proposal for an ESF Forward Look

– Submission to the Physical and Engineering Sciences Standing Committee –

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Content

1 Aim and objectives

Novel technologies that change lives by giving rise to shifts of behaviour and new businesses often stem from breakthroughs borne at intersections of scientific or technological disciplines. *Quantum, material and information sciences* have come to interact in such a way.

In a joint effort they have taken first steps along future technological pathways that will change the paradigm, for instance, in the way we measure precisely, apply sensitive sensors, transmit a highly secure message, compute a complex problem, or simulate a physical subatomic system in real-time.

Yet this is only the very beginning of new quantum information-based technologies, bearing some resemblance to the advances kicked-off by the early semi-conductor industry about 50 years ago. At that time, there were no 'break through applications' at hand, in sight, or envisioned (but instead first suggested applications for transistors were human hearing aids), and later the number of forecasted computers was envisioned less than a double digit number.

How things have changed. A lot of valuable lessons can be learned from the now 'traditional' information technology (IT) in terms of research and technological development as to how we have arrived where we are today, - and this is were open, unbiased, and science-based foresight exercises and forward (long) looks serve best.

The question for quantum information technology (QIT) then is the following – What's up next (or in other words: What is the 'quantum technology based hearing aid')? What roads will open up for future promising research and technological pathways as well as markets (and science business) development?

- Can we anticipate, envision, and include in today's decisions what types of pathways might emerge from quantum information science cross-disciplinary fields?
- Can we mobilize joint critical-mass action and walk these new paths, by making future-proof present-day decisions, through focused European scientific endeavour and applied R&D?

The ***Forward Look*** FARQUEST is designed as a prospective analysis and evaluation of technological roadmaps and scenarios that addresses these future pathways, which cannot yet be sufficiently planned or quantified.

It builds on expert dialogue and participatory integrative stakeholder processes (incorporating expertise and insights, e.g., from the sciences, science-based businesses, as well as funding bodies), with the aims to

1) systematically obtain projections of anticipated futures of quantum information science and its applications in yet unaddressed areas of high utilization;
2) identify the context & its features, trends, key drivers & inhibitors ("influencing forces"), and projections or future 'story lines' of (inevitable, predictable, uncertain) quantum information-based outputs & outcomes affecting science, businesses and social dimensions; and
3) evaluate impact and the future potential of new technological pathways for orientation and prioritization of European science policy, signals to monitor.

A further aim is to

4) have descriptive (state and progress of the field) and prescriptive functions (identifying what scientific, technology, skills, organizational, investment, infrastructure developments could be necessary to reach set goals) and; and

5) add value to the collective European knowledge bank of high-end science.

Keywords: quantum technology; information and communication; material science; computer science; advanced hard- and software engineering, basic science.

2 Project background and significance

2.1 Scientific scope

FARQUEST addresses the broader emerging technological field of ***quantum information science and technology*** (***QIST***), which has already demonstrated first significant advances and prototypical technological applications. It takes a **mid-to-long term view** at the research fronts of the **intersection of quantum information science with the other fields**, such as solid state and laser physics, material science, optics, supra-conductivity, electronics, mathematics, hard- and software, semiconductors and atom doping, traditional IT, as well as promising hybrid approaches between IT and QIT.

Over one hundred years of development in basic quantum science have produced one of the most precise theories, making highly accurate predictions in the realm of sub-atomic of condensed and free matter. Based on the foundations of quantum science, the last decade has witnessed first set-ups and investigations of man-made real-world quantum information systems, clearly demonstrating the application potential of quantum science and enlarging the field of basic research by applied science and science-based technology development.

Quantum science and technology exploits the quantum property of matter, by using prepared states of sub-atomic particles with specific properties. Among others it builds upon unconventional relationships between particles (e.g. so called “entanglement”) that cannot achieved through applications of the classical sciences; only recently have such advances moved out of the lab into first tests for technological applications.

Specifically, **two recent advances in quantum cryptography networks** – the transmission of fully secure messages between a sender and receiver that cannot be intercepted by third parties – **as well as a quantum computer** of simple, albeit steadily more complex systems. These applications **are “first breakthroughs”** in the sense that they are fundamentally novel, unparalleled, and open new windows of opportunity for lasting technological innovation through rigorous scientific insight, invention, and impact on public and private organizations.

2.2 Key questions & challenges

Research and development in QIST overall **still qualifies as “emerging”**; some future directions are plausible, while others remain nebulous, unmapped, or not yet envisioned. Importantly, enabling substantial and continuous progress in QIST depends on the development and **interaction of several different scientific and technological** disciplines.

Currently, the majority of topics pursued in QIST are rooted in basic research at universities and other research institutions. In order to make proper and synergistic use of the works and obtained results of these diverse groups, the cross-combination of additional expertise of other fields is required.

Moreover, the opinion of potential future users of outcomes (that is, what type of "problems" are to be solved, what "jobs" are to be done in future applications) – both of end users and industrial groups – is relevant to identify the focus for targeted basic research during the next phases of QIST development.

2.3 European context & potential added value

The situation can be viewed from two sides.

- On the one hand, European researchers and institutions are currently heading the scientific development in several topics of QIST. To name selected examples:

  1) several groups (e.g., at the University of Innsbruck, Austria, to name one national player but many others exists in Europe) played a leading role in the development of quantum-based computing;
  2) the FP5-FET (Future Emerging Technologies) unit launched for Quantum Information Processing and Communication (QIPC) in the realm of a Proactive Initiative more than twenty projects;
  3) it was continued under the FP6-FET with more than ten Proactive Initiative projects, among which the "QUROPE" project (http://www.qurope.net) was specifically devoted to support the European coordinated action in this field;
  4) the European project "SECOQC" (for Development of a Global Network for Secure Communication based on Quantum Cryptography and lead by the AIT – The Austrian Institute of Technology), funded under the FP6-IST Programme, joint together European groups in a world-wide leading role in quantum cryptography, by demonstrating a fully functional network secured by technologies based on quantum information for the first time ever; and
  5) another European project, which has been funded under the ERA-Net scheme (the ERA-Pilot "QIST"), contributed to begin to structure the scientific community and elaborated on a possible European roadmap for QIST, starting from a research scientific point of view (also under project involvement of the AIT).

  From a scientific perspective, so to speak, Europe has started to prepare for the competitive participation of the future development of QIST. This is momentum to keep, accelerate, and provide steadily attention.

- On the other hand, the European QIST-based start-ups, university or industry spin-offs, as well as traditional IT, businesses are not deeply involved. The successful conversion of scientific results-to-products for provider and consumer applications lacks the engagement of important industrial IT and interested hybrid (i.e. future IT/QIT) players that take over the responsibility for the final development (only they can and ought to do), to ensure the progress along the R&D value chain.

First attempts to include businesses with a stake in QIST were started (e.g. a standardisation group at the European standardisation organisation ETSI was founded and several European companies contributed to the development of standards for future application of QIST; currently with a narrow focus on quantum cryptography).

Nevertheless, scientific insights and the dissemination of results to businesses with a stake in QIST has to be substantially deepened and founded on a much broader basis to have significant impact beyond a mere exercise.

For a high-end science application like QIST, in that it shows similarities to the fields of the Life Sciences, only a joint effort will yield successful and future lead-proof progress.

2.4 Specific requirements for the study

The structuring process around QIST depends on the co-operation of the pertinent scientific community.

On a European level, this community is currently structured under the umbrella of the FET Proactive Initiative on "Quantum Information Processing and Communication" (QIPC), within the Future Emerging Technologies (FET) unit now of the FP7 programme that organises meetings and conferences on a regular basis. Here the **Austrian Institute of Technology** fully resides in this community and has already established existent contacts to the corresponding FET unit; the AIT is enabled and capable to utilize existing contacts to coordinate the FARQUEST related activities with measurements taken on the European level.

In addition, businesses with a stake in R&D activities are coordinated mainly under the agenda of the ETSI (European Telecommunications Standards Institute). Here, the AIT is actively involved too (e.g. in the Industrial Standardisation Group is chaired by an AIT member). The AIT will distinctively use its twofold involvement in both groups to co-ordinate and structure the FARQUEST foresight process to successfully achieve its objectives.

2.5 Potential expertise of stakeholders and partners necessary to achieve the objectives

Research scientists residing in universities or similar institutions and scientists & engineers in science-based businesses have different contexts, work in different environments, measure outcomes differently, and sometimes communicate in different "languages".

One side too often hardly understands what the other side is on to right now; only rarely are there are common-ground spaces (e.g., meetings, forums for exchanges and dialogue, common vision building), where both "sides form a whole" to share their respective expertise and exchange their knowledge – in order to take up problems of businesses with a stake in QIST or to show out-of-the-lab approaches for completely new technological components at an early stage.

Moreover, there is very little co-ordination, say, with industrial roadmaps and long-term perspectives of science & technology policy development.

Based on previous projects (e.g. the ERA-Pilot QIST), there are "seed contacts" to several players of technology policy-making in Europe, and the AIT's participation in the ETSI-standardisation process provide access to the relevant industrial players that are interested in the progress of Quantum Information. This can be purposefully used to bridge science, industry and policy and to establish forums for dialogue-based exchange and network discussions to foster knowledge and novel insights – bringing synergistic advantages for both the academic and science-based businesses active in the fields of QIST, by re-aligning the community to *what is up next*.

2.6 Expected results & lead users of the outcomes

- General considerations

  First, the foresight project FARQUEST serves to raise pointed awareness among the broader scientific community, R&D in science and technology-based businesses as well as funding bodies about the past, current and future advancements, implications, and impact of QIT on several dimensions.

  It further serves to provide orientation for directing science policy at the national and European level. For QIST draws from scientific experts and stakeholder groups from both

academia and industry, a joint undertaking will increase the quality (in terms of process and outcome) of the FARQUEST foresight exercise, with strengthening links between university and non-university research.

- Stakeholders of the scientific community

  European scientists at various stages in their career development can focus on important, unaddressed, and highly utilizable (with added social surplus dimension) research topics and needs, centred on their own fields or a cross-disciplinary involvement of basic and applied quantum information science and technology.

  The conducted research holds higher potential to make significant contributions for science & technological innovation, with incentives to tackle high-impact and reward studies, and thereby gain individual recognition among peers. It highlights common objectives, perceived needs for collaboration within and between stakeholder groups, and it strengthens the European network and networking opportunities in the fields related to QIST.

- Stakeholders of the science and technology-based businesses

  Commercialized R&D is enabled to focus with increased effectiveness and efficiency on early stage movements of about-to-become real technological paths, by building on joint efforts with academic research, finding standardizations, research aligned science business development, and deeper embedding of the value chain.

- Stakeholders of the funding bodies

  Obtain practical orientation knowledge and recommendations for action about the high-end science and technological field of QIST, by being provided results that can be linked to the science policy discourse, optimize the set of possible policy instruments for research, and eventually new science policy. FARQUEST fosters the collaboration between different national organisations with a stake in QIST and provides direct contact to existing networks in the scientific and science-based business community.

  FARQUEST supports the structuring of European-level research in the fields of QIST (networking, coordination of national research programmes) and inputs recommendations for a combined European strategy to secure the strong lead of QIST science and technology in Europe (learning lessons from developments in semi-conductor science & technology).

3 Project planning

3.1 Project preparation

Scoping workshop, I. Preparing and holding a “scoping workshop” (in Vienna, in winter 2010) to discuss and finalize the proposal.

The main goals of the scoping workshop are centred on the identification of the 1) general scientific questions in the area and 2) societal questions related to the subject; 3) key players and stakeholders and 4) targeted audience, as well as 5) needs for the community and the industry; 6) SWOT analysis for the domain in Europe; and 7) set up of working groups (WGs): potential chairs or participants, general questions for each WG, specific questions to be addressed during the activities, and potential foresight methodologies.

The workshop (I) involves the core team and selected members of the community; and possibly a member of the ESF.

Finalizing workshop, II. Preparing and holding a second workshop (e.g., in Strasbourg, Brussels, or Vienna) to finalize the set of foresight activities and gain acceptance by the Scientific Advisory Board of the ESF.

If successfully, the actual Forward Look starts. The ultimate goal of the Forward Look is several-fold, and roughly includes descriptive and prescriptive roles as well as bringing together experts from various fields joined in quantum information science and drawing recommendations for research policy in this field.

The workshop (II) involves a larger audience, including funding agencies and other stakeholders.

3.2 Project plan

- FARQUEST first aim is to deliver tangible output (that is, results); its second aim is intangible, by building and fostering social networks between scientists from academic and industrial research.
- The Forward Look will be steered by ESF project management in close interaction with the AIT core them (process management). It will include serial interactions between contents & methods[1], on the one side, and dialogue-oriented stakeholder forums with different stakeholder groups on the other.
- With the focus on the big picture, it will use bibliometric analysis to survey the past and current fields of quantum science and technology, workshops with network ("world-cafe") conversations between thematic expert panels & brainstorming, trend-extrapolation of key indicators, portfolio techniques, wrap-ups and structuring by scenario-drafting pertinent to the drivers, forces and scenarios, and a consensus conference open to reflection.

Planned duration of the project

- 12 to 15 months (start-end of entire project).

Expected budget

- Pre-ESF Forward Look activities: €10.000.
- ESF Forward Look: about €200.000.

4 Appendix

4.1 AIT – The Austrian Institute of Technology

The AIT is Austria's largest non-profit applied research institution, equally owned by the Austrian government and a group of industrial partners. Originally founded as a division of the AIT in 1989, the Department of Foresight & Policy Development (today) became a separate legal entity and a 100% affiliate of the AIT in the year 2003. It is centrally located in Vienna.

Today, AIT-Foresight & Policy Development consists of five thematically organized internal departments: Technology Management, Technology Policy, Technology Transfer, Regional Studies, and Environmental Planning. It has about 50 employees, most of which is scientific personnel with overall broad backgrounds ranging from socio-economics, social and political sciences to electrical and chemical engineering, physics, or mathematics.

The main research activities include, for instance:

- innovation studies, with a the focus on the systemic analysis of sectoral, regional, national and international innovation systems;
- strategy consulting for educational and corporate organizations, with the focus on foresight and socio-technological scenarios;
- the design and evaluation of concepts, strategies, programmes and instruments for science, technology, and innovation policies;
- the innovation and knowledge management in public and private organisations; or
- the development of scientific indicators, tools for bibliometric and science and technology monitoring.

AIT-Foresight & Policy Development also draws on the expertise of the AIT as a whole, with over 900 employees conducting research in advanced information technology, materials and the life (health) sciences, as well as mobility, energy and transport.

AIT-Foresight & Policy Development seeks multi-disciplinary research with a focus on the systemic analysis of scientific, social, economic, and ecological systems. In this role, AIT-Foresight & Policy Development is supporting national and international science, technology, innovation, and environmental policies in their strategic orientation. As such, it not only constitutes a node in national and international research networks, but does make significant contributions to the development of both educational and corporate strategy development.

The AIT is certified according to the international Quality Management standard ISO 9001 resulting in state-of-the-art quality management in all its business processes.

4.2 Accompanying graphical illustrations

Figure 1. Three foundations of FARQUEST's participative stakeholder groups approach: 1) basic be influential in the future and applied research in the interdisciplinary field quantum information science; 2) industrial research in quantum technologies and prototypical applications and scenarios; and 3) science strategy map and policy making and funding of frontier research that will prove to

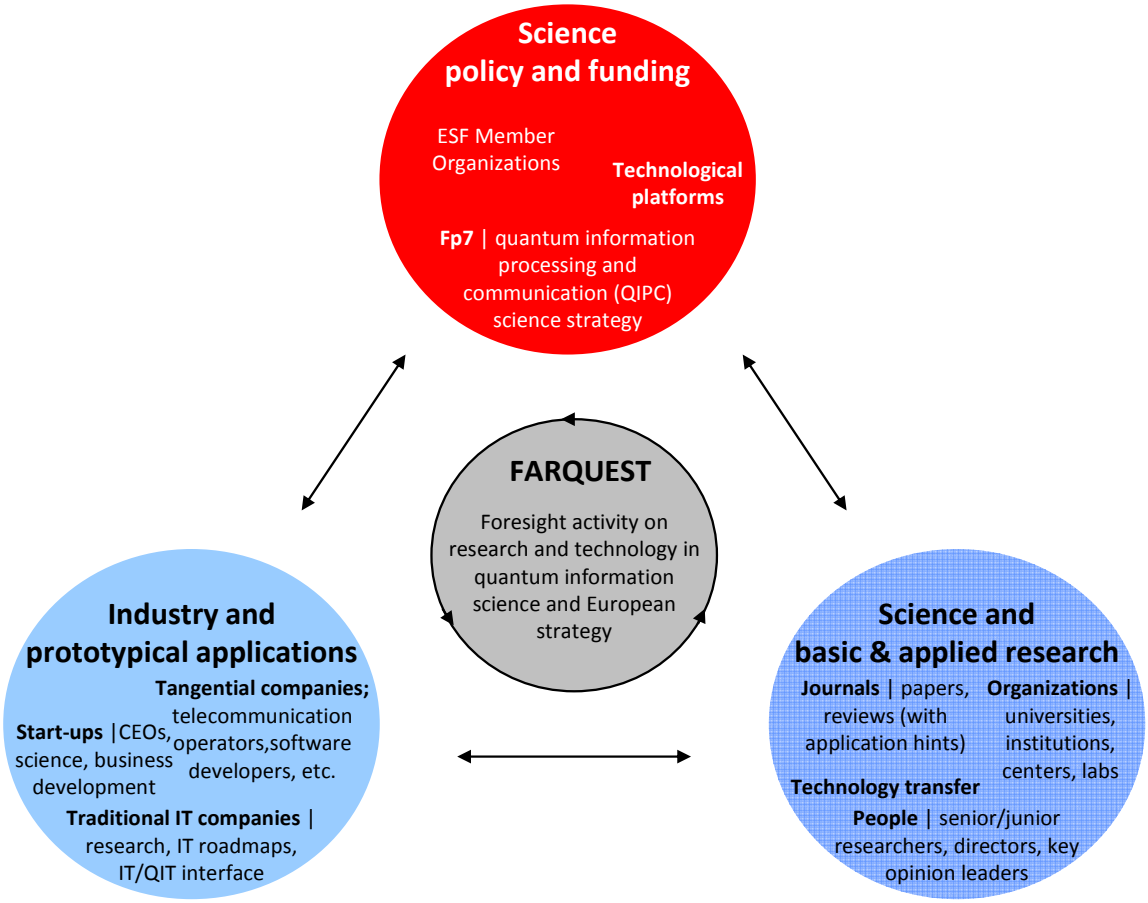
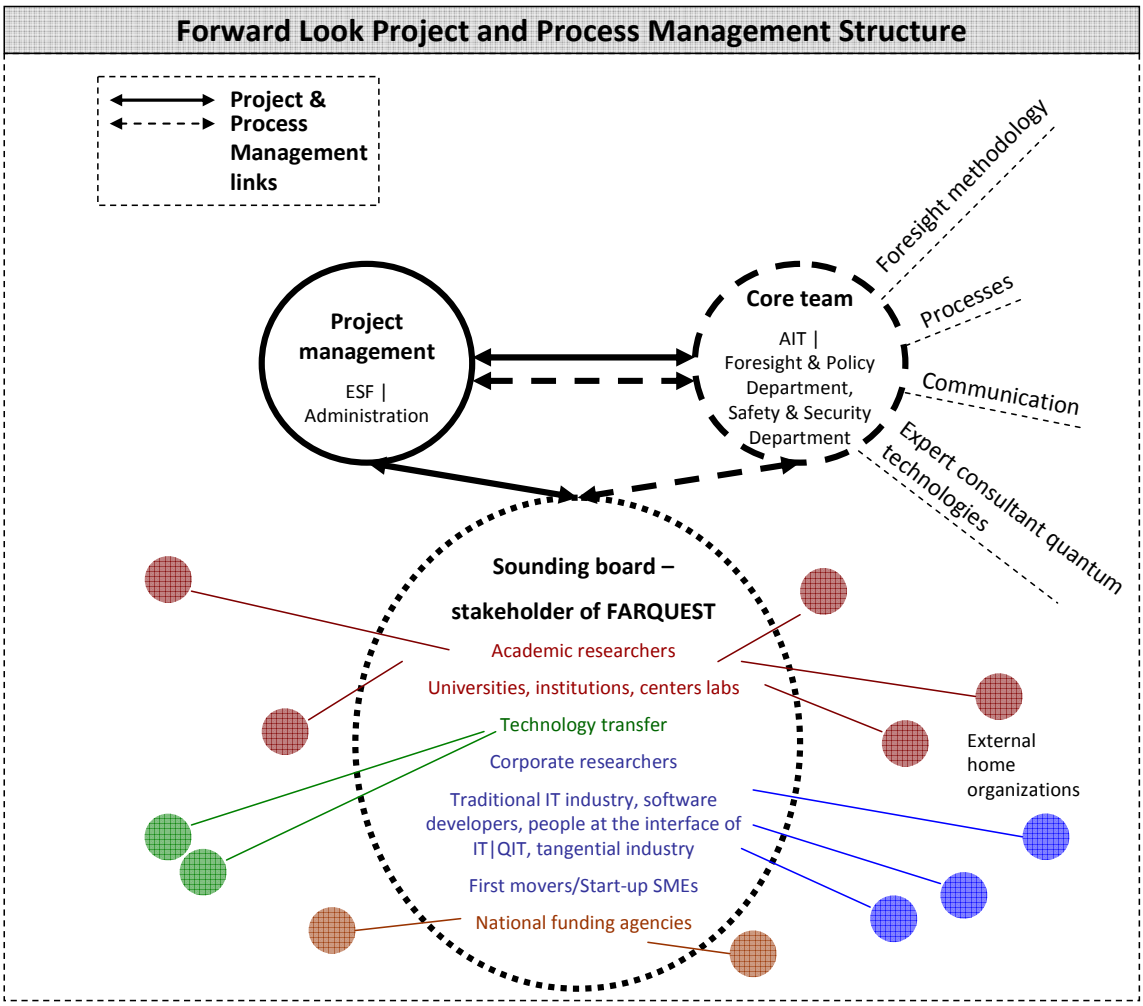


Figure 2. The ESF Forward Look project management and Forward Look process design & organization is broken down into three larger interacting entities of project management; process management, communication, and expertise; and a stakeholder sounding board[1].



[1] Holste, D., Kubeczko, K., Schartinger, S., and Wilhelmer, D. *A complementary architecture to build foresight*. Paper presented at the ISPIM – The XXI ISPIM Conference Dynamics of Innovation Bilbao, Spain, 6-9 June 2010 (http://www.ispim.org/files/ISPIM_2010_Conference_Programme.pdf).

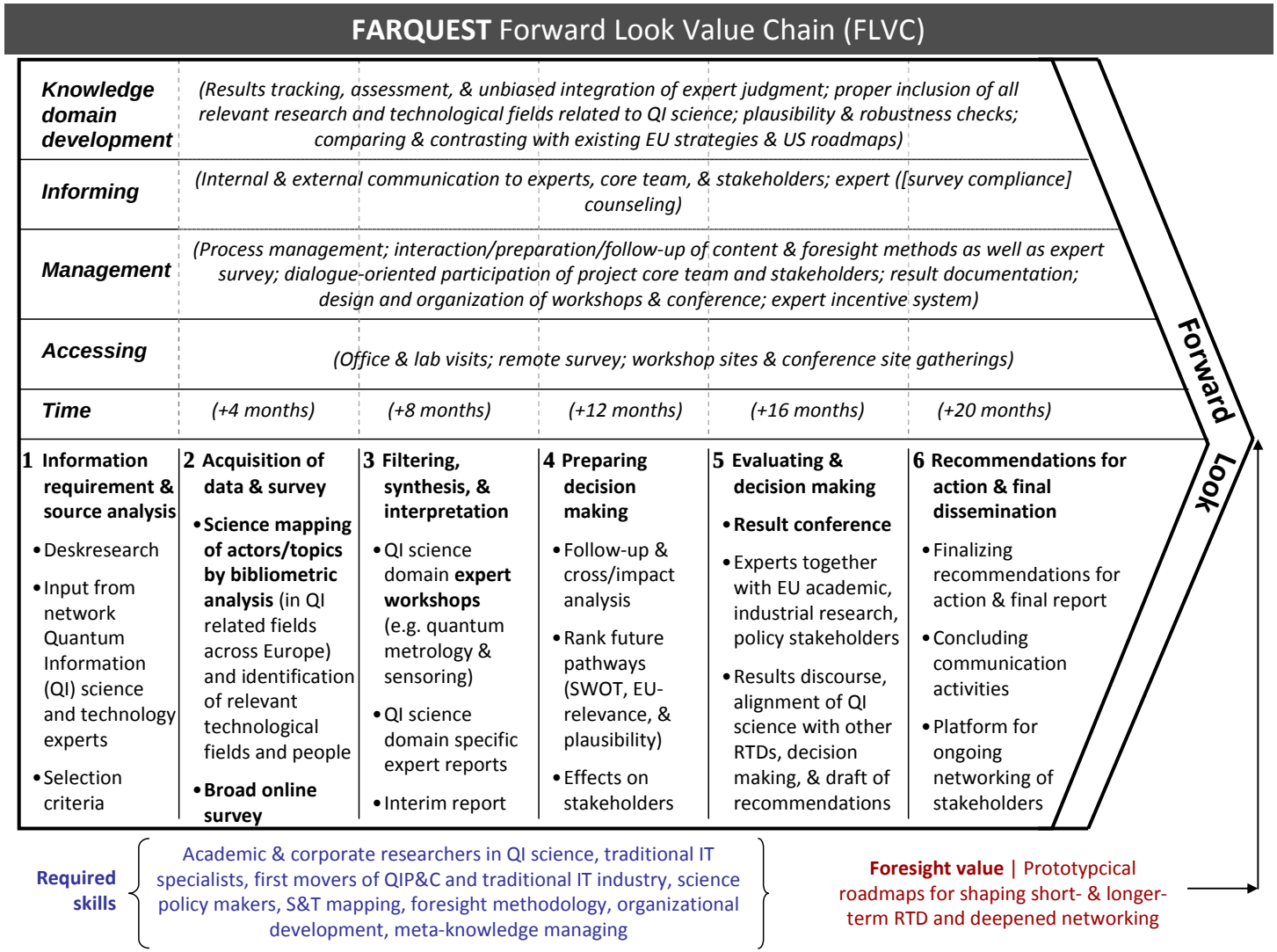


Figure 3. The FARQUEST value chain for process design & management is presented as a sequence of six interacting steps; five design objectives are embracing the full sequence of steps and ensure the proper organization of the Forward Look, the quality of the results, and the delivering of the objectives.

Figure 4. The sequence step 2 involves an unbiased, fair, and efficient bibliometric approach to identify influential scientific publications, topics in quantum information science, and authors/experts for the initial survey of research fronts – subsequently deepened, dialogued, discussed, explored, and formulated as (mini)roadmaps in workshops and the consensus conference.

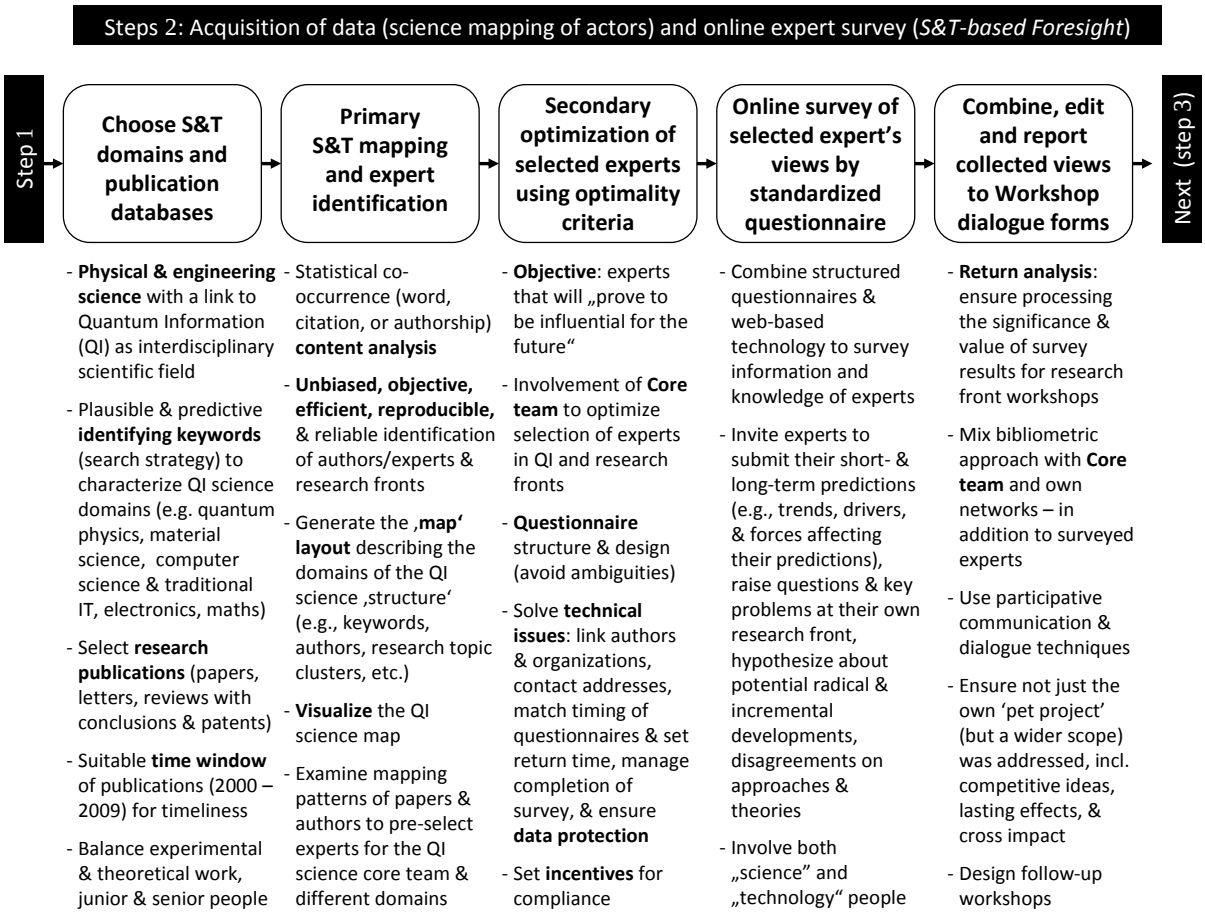


Figure 5. The sequence step 2b – an illustrative example (performed for the science and applications in the field of "quantum key distribution") of selected bibliometric-support for the identification of experts and topics in relation to quantum information science.